A Simple Method for Improving Control Area Performance: Area Control Error (ACE) Diversity Interchange ADI

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***Abstract* - Control Areas within three major (and essentially separate) areas of North America are interconnected electrically, thus enjoying vastly improved reliability and economy of operation compared to operating in isolation. Each must continually balance load, interchange and generation to minimize adverse influence on neighboring control areas and interconnection frequency. This requires investment in control systems and the sacrifice of some fuel conversion efficiencies to achieve the objective of complying with minimum control performance standards set by the North American Electric Reliability Council (NERC). Control also increases wear and tear on machinery in the pursuit of these goals. Area Control Area (ACE) Diversity Interchange (ADI) offers a means of reducing this control burden without undue investment or sacrifice by any participant in a group. This paper describes the philosophy of ADI and the ENEREX partnership's favorable experiences with its actual implementation in Iowa.**

I. INTRODUCTION

ENEREX is a three-company partnership in Iowa dealing primarily in bulk-power exchange among its members: Iowa Electric Light & Power (IESC), Iowa-Illinois Gas & Electric Co. (IIGE) and Midwest Power Systems Inc. (MPSI). ENEREX began as a five-company partnership in 1984 and has "lost" two partners through two mergers of pairs of the original partners. Iowa Power and Iowa Public Service became MPSI in 1992 and Iowa Electric Light & Power and Iowa Southern Utilities became IESC in 1993. All ENEREX partners are small-to-medium sized control areas operating in the Mid-Continent Area Power Pool (MAPP). Their peak demands range from approximately 1100 MW (IIGE) to approximately 2300 MW (MPSI).

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ENEREX has the capability to exchange data on an Automatic Generation Control (AGC)-cycle basis (every four seconds) using a specially-adapted SCADA system. This system has primarily served to allow interchange of control information for shares of jointly-owned generating units (JOUs), but is now being used for another novel purpose as well. That purpose is the interchange of diversity schedules for the dynamic correction of Area Control Error (ACE). Control of ACE is a costly affair for every control area in all electrical interconnections in North America, including the Eastern Interconnection of which the ENEREX companies are a part. However, proper control is a necessary responsibility for maintenance of interconnection frequency and localized stability in the electric systems. The North American Electric Reliability Council (NERC) sets standards for realization of this responsibility, measured by "Control Performance Compliance" (CPC) percentages [1]. The purpose of ACE Diversity Interchange (ADI) is maximum mitigation of the required control effort to achieve acceptable CPC percentages based on available diversity among a group of participants. All it requires is two or more control areas willing to participate, a means of communicating data on a real-time basis and calculation software at a common site.

II. AREA CONTROL ERROR

ACE is defined [1] as the difference between actual net area interchange and scheduled net area interchange, with a component for frequency bias. Since the ACE calculation uses instantaneous information, the interchange is power, stated in Megawatts, rather than energy, as used hourly. In "classical" equation form (calculated each AGC cycle):

$$\mathrm{ACE} = (\mathrm{Ni}_a - \mathrm{Ni}_s) - 10B(\mathrm{F}_a - \mathrm{F}_s) \qquad (1)$$

where:
Ni_a - Net power interchange (actual)
Ni_s - Net power interchange (scheduled)
B - Bias (Megawatts/0.1 Hz, unique for each control area)
Fa - Frequency, actual (measured)
Fs - Frequency, scheduled (normally 60.000 Hz)

As referred to in this document, raw ACE is the error value calculated by any ADI participant based on its own schedules and telemetered interchange prior to any filtering or the effects of ADI. A "cycle" is one AGC calculation cycle, usually four seconds. ACE is the basis used by Automatic Generation Control (AGC) algorithms in establishing the way in which a control area's generation resources are allocated to balance requirement with output.

III. THE ADI SCHEDULING PROCESS

A. *Premises*

ADI works on the assumption that instances occur in which one or more of the ACEs of the participants (of course, there must be two or more) are of opposite sign from one or more others. Whenever this is the case, there is diversity which can be exploited to partially or wholly correct the raw ACE of some or all participants. The ENEREX ADI algorithm ensures that no calculated schedule ever makes any raw ACE worse...it will always move raw ACE toward zero or do nothing to it.

Protective parameters must be provided to eliminate undesired corrective action on the part of the procedure, namely:

- Maximum allowable (reasonable) raw ACE value
- Maximum allowable rate-of-change of raw ACE
- Deadband for acting on raw ACE value received
- Maximum allowable ADI schedule sent to participant
- Maximum rate-of-change of schedule

An additional "switch" is provided which can remove a participant from the procedure instantly. It has rarely been used but is a convenience to the participants. The parameters are provided for the convenience of the participants and may be changed at their request without delay.

B. *Method*

Steps in Calculation of Schedules (each AGC cycle):

- All ACEs are received and limits applied according to each participant's Maximum values and Maximum rates-of-change. Further limitations are imposed by ignoring (zeroing the ADI schedule) of any participant whose raw ACE is inside its deadband.
- Diversity is tested for (is at least one raw ACE opposite in sign from others?). If none, all ADI schedules are set to zero and the algorithm waits until next cycle.
- If diversity exists, positive and negative ACEs are separated into two groups, usually one smaller and one larger. Zero or ignored raw ACE values are set aside and each of their participant's schedules set to zero.
- Schedules are set for the Small Group (SG). Since the Large Group (LG) will be able to supply all the diversity needed to zero the SG, all the SG's schedules are set to their raw ACE value, which will zero their ACEs. Note: by convention, a schedule of the same sign and magnitude as ACE will zero ACE.
- SG's ADI schedules are checked for violations of rate-of-change or maximum size. Any that require it are reduced.

Schedules are then set for the Large Group:

- Begin with the smallest raw ACE and prorate ADI schedule(s) to each (ith) member of the LG:

$$Sched_{LGi} = \frac{ACE_{LGi}}{\sum ACEs_{LG}} \times \sum Scheds_{SG} \quad (2)$$

(each amount is rounded until the last LG participant)

- Set last (largest raw ACE in the LG) ADI schedule to the remaining unused diversity amount to avoid rounding problems.
- Check LG schedules for violations of rate-of-change or maximum size. Any that require it are reduced.
- If reductions in LG schedules were made, scan other members of the LG for any additional diversity which they could provide above the amount calculated in above. If additional MW are available, utilize them in prorated fashion up to the point where they are exhausted or the total ADI requirement for the SG is satisfied.
- If, after this search, reductions in the LG schedules leave the SG short of needed ADI MW, return to the SG and reduce interchange using the same technique as in (2) above to balance the two groups.
- Transmit schedules to participants.
- Increment MWh accumulators (for end-of-hour energy calculations). MWh schedules are transmitted to participants at the end of each hour for their energy accounting.

IV. INTERFACING WITH PARTICIPANTS

ENEREX uses a small, PC-based SCADA system for data interchange. To interface with ENEREX ADI, each participant has defined a data point for raw ACE to be sent to ENEREX and a schedule to be received from ENEREX. Hourly database points allow transmission of the resulting integrated received and delivered MWh amounts.

Time delay (skew) exists in every SCADA system. Participants' ACEs are the products of sequential sampling systems which have inherent time delays in their components. Participants must be aware that while the ADI schedule sent to them will properly correct a raw ACE that is known at a given point in time, delay in data transmission could occasionally cause the schedule to make ACE look different than it ideally should. Tests have shown the actual delay in "turnaround" (the time between a participant's transmission of raw ACE and receipt of a corresponding ADI schedule) to be 8-12 seconds, which has an effect on the appearance of ACE but has almost no effect on the overall improvement in CPC performance percentages. Because of time delay, it has been advised that a software check be made in the participant's AGC software, where necessary, to allow generating unit controls to ignore the effect of the ADI schedule if it momentarily makes ACE worse (this should already exist in some form in most AGC systems). Deadband values must be chosen to minimize this effect while allowing ADI to do its job.

V. GENERATING UNIT CONTROL EFFECTS

A. *ADI Schedule Usage*

ADI scheduling either reduces raw ACE or leaves it unaffected. ADI-corrected raw ACE should be used to supply AGC. If this is made so, generating units will not have to "chase" ACE as much, since ACE movements will be reduced. If the schedule is ignored by AGC, ACE (on the chart) will be improved along with NERC performance criteria, but units will still "chase" raw ACE as if ADI were not there. Note, in Figure 1, that the ACE fed to AGC may come from the summation calculation (raw ACE plus ADI schedule, or ADI ACE) or from raw ACE.

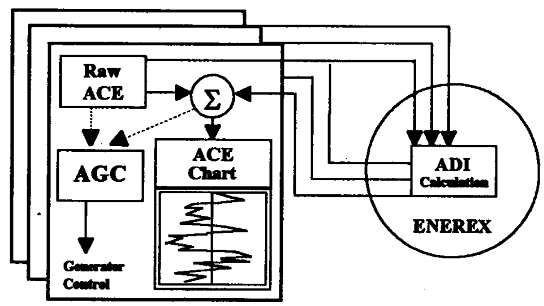


Figure 1 - ADI Information Flow and Usage

B. *Undesirable Schedule Settling*

"Settling" is a term used to describe a condition where ADI participants all use ADI schedules to affect control and as a result offsetting schedules may zero participant ACEs, causing their AGCs to "settle" their generating units at levels which do not change the schedules. In AGC systems that calculate Economic Dispatch based upon total generation rather than generation requirement, pairs or groups of participants may be held off economics for indefinite periods. Experience has shown this to occur, although infrequently. A reactive approach may be a permissive ADI algorithm which monitors duration of the schedule(s) may be installed to taper the schedule to zero if its duration is considered excessive (usually in excess of 10 minutes and 10 MW). Another approach suggested has been for participant AGC to recognize the duration of the schedule (integrate it) and limit the permissible integration value. The latter solution is difficult to implement across a group of participants due to delays and difficulty in changing AGC software. The extent of and constraints on this phenomenon will vary with the size of the participant system(s).

VI. EFFECTS ON THE INTERCONNECTED SYSTEMS

The ADI schedules exchanged every 4 seconds net to zero. The effect on participants is in reducing raw ACE to the extent possible, and decreasing generating unit corrective action. The immediate net effect on the interconnection is either nil, in the case of participants who only use raw ACE to drive AGC, to small, in the case of groups using ADI-corrected ACE in AGC. The small effect results from the net reduction in units chasing ACE within participant control areas. This net effect may cause the total momentary net inadvertent of the group to be either larger or smaller than it otherwise would have been, but taken as a whole the effect must be small since CPC percentages must be maintained at acceptable levels.

Under ADI a portion of what would otherwise have been inadvertent energy for a control area with the interconnection as a whole is diverted to reduce other companies' inadvertent, in return for which the inadvertent of the company in question is reduced (and performance improved). Since the total absolute inadvertent of the group is reduced, inadvertent energy payback at future times outside the group is correspondingly reduced.

After-the-fact repayment schedules are made in such a way as to ensure that each hour they net to zero, also. A possible benefit to the interconnection is in that the inadvertent account of each ADI participant is held to a minimum, which also minimizes the necessity for that control area to unilaterally balance their account. This, in turn, may reduce the accumulated inadvertent of other non-participant control areas in the interconnection, as well as the perturbations of frequency that at times accompany payback.

VII. ENERGY ACCOUNTING

The interchange of periodic energy schedules to correct raw ACE and the repayment of accumulations of such energy is classified as inadvertent repayment, as defined in the NERC Operating Manual [1]. This type of payback is multilateral rather than bilateral or unilateral, but may be prorated if necessary to determine bilateral schedules. <u>The ADI method is in the same spirit as bilateral inadvertent repayment, but encompasses more participants.</u>

The integration (accumulation) of the ADI schedules to calculate hourly energy involves totaling 4-second-based MWh values, received and delivered, during an hour. At the end of the hour, the totals are divided by the number of 4-second intervals in the hour (900) and the result rounded to the nearest whole number. Each hour's schedules are assured of balance by testing for same, then affecting the rounding of accumulated schedules as necessary to balance receipts and deliveries (to net zero). The remainders from the integration process (fractional MWh) are carried forward and added to the next hour's beginning accumulations.

Integrations of ADI schedules produce hourly delivered and received totals for each participant. Each day, their sums produce **on-peak** (hours ending 0700-2200) and **off-peak** (hours ending 0100-0600 and 2300-2400) net energy accumulations as if between each participant and ENEREX. These accumulations are reconciled (verified) between ENEREX and each participant daily. Energy balances are accumulated (as if to ENEREX) each hour and are repaid weekly as needed. Balances larger than predetermined limits (HIGH THRESHOLD) are scheduled with the participants by ENEREX accounting to bring them back within limits (LOW THRESHOLD). Since ADI is bi-directional and somewhat random, large energy accumulations in any given direction do not occur for any one participant in a week. During the first 6 months of permanent use of this procedure in ENEREX, hourly energy accumulations from ADI averaged just over 1 MWh/hr for a typical participant.

VIII. TUNING PARAMETER SELECTION

In order to gain maximum benefit from ADI, participants must not over-constrain the ADI system by use of restrictive tuning parameters. Each parameter and its intention and effects is mentioned below:

- Maximum Allowable raw ACE

The raw ACE which is used by the ADI calculation is limited to a selected maximum value. It is a reasonability check on values which may be of questionable accuracy. Initially, this value was left large (100 MW for the ENEREX partners) to allow for large ACE values to be recognized, yet reject anomalously high ACEs. It remains at 100 MW for all participants a year after inception of ADI.

- Maximum Allowable Rate-of-Change of raw ACE

Limits the raw ACE recognized during the current 4-second interval to the raw ACE in the last interval plus-or-minus the allowable rate-of-change. It is both a reasonability and a filtering parameter. It, too has been left large (100 MW/cycle).

- Maximum Schedule Returned to Participant

Specifies the largest schedule allowable for a given participant in ADI. Most are set to 100 MW, although one participant was reduced to 30 MW temporarily during solution of the "settling" phenomenon.

- Maximum Rate-of-Change of Schedule

Restricts the change in schedule from one cycle to the next.

- Deadband for Acting on raw ACE Value Received

This is <u>the most important tuning parameter</u> relative to time delay. It allows only raw ACE values which fall outside its boundaries to be recognized. It is thus possible to ignore small raw ACE values...the ones most likely to be small enough to be adversely affected by time delay. The value for deadbanding has been kept small...definitely less that L_d [1] (a NERC control criterion parameter unique to each control area), or ADI's beneficial effects will be hampered. A typical value for deadband is 3 MW in the ENEREX control areas, while L_ds average approximately 10 MW. Figure 2 illustrates what effect deadbanding has on ADI and ACE, where the narrow trace represents raw ACE and the thick trace shows corrected ACE:

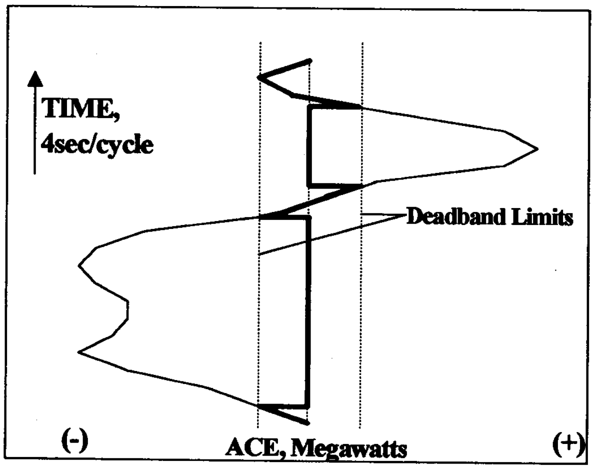


Figure 2 - ADI Deadband Effects

The larger a participant's deadband, the less opportunity there is to correct raw ACE when diversity is present. In the figure above it has been assumed, for simplicity, that enough diversity was always available to correct raw ACE to zero. If less is available, ACE will not move completely to zero when ADI is applied.

IX. BENEFITS OF ADI

A. *Efficiency Improvement*

Regulation for control costs money. ADI, when applied to a participant's control algorithm, reduces the cost of regulation.

The ENEREX partnership began ADI on a permanent basis January 1, 1993. It has run continuously since that time. It is not precisely known what the value of the reduction in regulation through ADI is worth in dollars. Its worth includes both efficiency gains and wear-and-tear (also called Operation and Maintenance, or O&M) cost reductions. The value of ADI to the ENEREX partnership has been approximated at $400,000 per year. This figure is based on efficiency gains, only. Wear-and-tear costs are much harder to quantify and were not included in the estimate.

B. *NERC Control Performance Criteria Compliance Effects*

During the first six months of ENEREX's use of ADI, improvement was seen in CPC percentages relative to what had been experienced in the past. This improvement ranged 2-7% across what was at that time four participants. This improvement is real and can be said to represent an actual increase in performance.

In looking at a comparison of raw ACE performance versus ADI ACE performance, a different picture emerges. Each ENEREX partner used ADI ACE to feed AGC, which allowed generation to "relax" and not respond to raw ACE. It is important to be aware that when ADI is used in this way, CPC compliance for the ADI ACE is very real but the performance of the raw ACE is no longer representative of what the participant would have done without ADI. Rather, it shows the extent to which AGC and the generating units were able to "relax" and reduce their pursuit of the raw ACE. This caveat in no way dilutes the effectiveness of ADI, it just cautions the reader to interpret the results in the proper way.

Figures 3a and 3b show the CPC percentage differences during the first 6 months of 1993 for the ENEREX partners. These CPC percentages represent statistics compiled continuously (every four seconds) for the 181 days January 1 to May 31.

A1 %	IELP	IIGE	MPSI	ISU
Raw ACE	83.6%	77.4%	62.7%	81.2%
With ADI	94.0%	90.5%	81.7%	92.4%

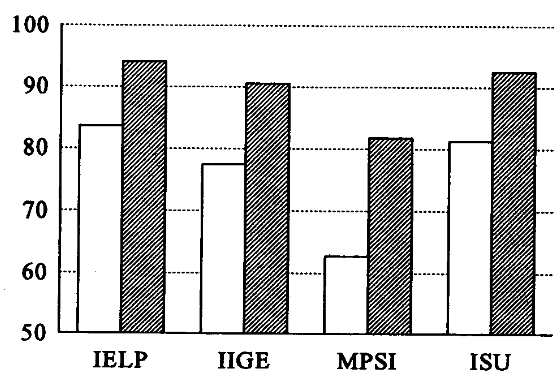


Figure 3a - A1 Performance Comparison

A2 %	IELP	IIGE	MPSI	ISU
Raw ACE	90.8%	72.1%	72.7%	89.1%
With ADI	96.5%	84.1%	83.8%	94.7%

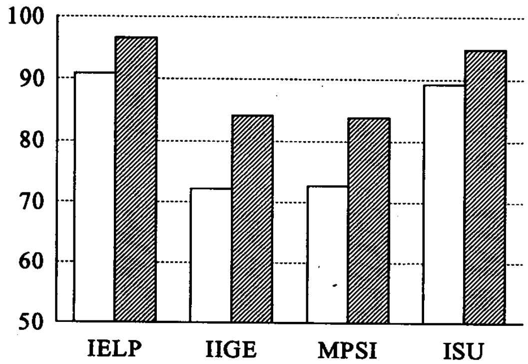


Figure 3b - A2 Performance Comparison

X. CONCLUSIONS

The ENEREX experience with ADI has been a fruitful one. Now that the process is running on a permanent basis, it needs almost no attention to operate properly and provide ongoing benefits to participants. For those control areas which may be willing to undertake implementation of ADI, the process only requires two or more participants, the communications interface to exchange the data and a computer on which to effect the necessary calculations.

Potential problems to be aware of are:

- Time delays in communications
- "Settling" of schedules when ACEs are zeroed
- Data loss due to hardware or software malfunction (Enough data should be saved to reconstruct)
- A2 performance violation phenomenon...can be handled algorithmically

The last problem needs additional treatment. When other participants in a group need schedules in a given direction to correct their ACEs and one or more other partners' ACEs are swinging back and forth across zero, the "other" partners will experience a zeroing (or nearly so) of raw ACE on one side of zero and no effect on the other side. This causes a sort of "half-wave rectification" of their raw ACE which will shift its average value. If the average is shifted far enough during a ten-minute interval, an A2 violation may occur where none existed in the raw ACE. This problem can be looked for by software and corrected or simply left alone. The occurrence of such violations was observed about five times in six months of operation (representing about 104,000 total ten-minute intervals for four participants).

There remains no question in the ENEREX partnership that ADI is a worthwhile, low-cost way to achieve some benefit of combined operation while upholding the autonomy of the separate control areas.

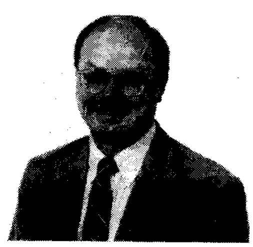
XI. ACKNOWLEDGMENTS

The author respectfully acknowledges the philosophical contributions of Loren R. Walker and the support of the ENEREX Executive Committee, Operating Committee and programming staff in bringing this project to reality.

XII. REFERENCES

[1] North American Electric Reliability Council (NERC) Operating Manual.

XIII. BIOGRAPHY



Alan R. Oneal is a native of central Iowa, graduating with a BSEE from Iowa State University in 1971. After a tour in the US Army (1972-74) he returned to private business in electronic design and maintenance. In 1978 he began employment with Iowa Power & Light Co. in Des Moines, Iowa in their System Operations department. Three years later he moved to planning with Iowa Power. After three more years in planning, he became involved with the development of the ENEREX project working toward a five-company partnership for a combined control area. In 1984 he joined ENEREX as Superintendent of Operations and was promoted to Manager in 1989. He is currently serving on the NERC Performance Subcommittee as Survey Coordinator for the Mid-Continent Area Power Pool (MAPP) and is a participant in FEMA's Emergency Electric Power Executive Reseıve program. ENEREX continues to serve the remaining three partners through data exchange, bulk energy interchange scheduling and ADI.

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